Three-dimensional Numerical Analysis of Ground Vibration Induced by Subway Running

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Abstract

Based on the finite element software ANSYS, the paper establishes the rail-track plate -tunnel-soil dynamic interaction finite element model. Wheel/rail forces are applied to the finite element model for calculating transient analysis. From the point of view of time domain and frequency domain, the paper analyses the influences on the vibration characteristics of the earth's surface caused by factors such as the rule tunnel buried depth, soil elastic modulus, up line and downlink tunnel distance. The analytic results show that the increasing tunnel buried depth can effectively reduce the surface vibration. Elastic modulus of soil has great influence on the surface vibration, with the increasing soil elastic modulus, the vibration response of the ground first increases then decreases. Increasing the net distance between double line tunnels is one of the measures to control the ground vibration.

Keywords

3D Finite Element Model; Vibration; Acceleration; Time Domain; Frequency Domain

Introduction

Underground railway has many advantages, such as large capacity, high speed, safe and reliable, running on time, etc. Because of these outstanding advantages, it becomes an important means to solve the urban traffic jam. The vibration waves induced by metro train's running go through rail, track plate, tunnel by the rock and soil medium to ground surface and surrounding buildings spread foundation, further causing the vibration of the earth's surface and adjacent buildings. Many experts and scholars have done a lot of research and obtained a series of results about the ground vibration induced by the subway (Xia and Cao, 2004) and their control measures (Hao et al., 2008).

Rail- track Plate - tunnel - the Finite Element Model

Environment vibration induced by the subway trains is the space problem of vibration wave propagation in 3-D. Due to the restrictions of computational efficiency, numerical simulation of the finite element model is usually the two-dimension plane model (Feng et al., 2007). While two-dimensional model saves time and cost, but the results are not very satisfactory. L. Andersen established two-dimensional model and three-dimensional model, combining with the finite element and boundary element; the results show that the two-dimensional model is only applicable to qualitative earth vibration caused by subway analysis (Andersena and Jones, 2006). Xiaoyan Lei finds that the two-dimensional model assumes that wavelength is infinite along track direction, it causes that the mobile wave along the track and the load is out of consideration (Lei and Sheng, 2008). In order to simulate the characteristics of vibration wave propagation in three-dimensional induced by the train running under the ground more accurately, the paper establishes the three-dimensional rail-rail plate-tunnel-earth finite element model based on the ANSYS software. Subway train vertical wheel/rail force on the track is simplified as a moving train axle load as Fig. 1.

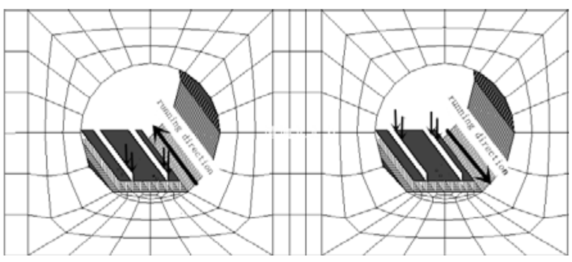

FIG. 1 WHEEL RAIL FORCE LOADING

Model Parameters Selection

Geological parameters of the model gained by geological reports from China NanchangNo.1 subway line BaYi square to Zhongshan Road section and some are got by calculating the parameters if not given in geological report. Considering to the smaller strain material, soil is assumed to be homogeneous soil; all the materials are always in elastic state. Calculation parameter of rail: Ec=2.1x10^5MPa, ϱ=7830Kg/m^3, μ=0.3; parameter of concrete materials: Ec=2800MPa, ϱ =3000Kg/m^3, μ =0.2; parameter calculation of fastener: K= 5 x 10^7N/m, 5 x 10^4Ns/m; The principle of stiffness and damping equal, the CA sand layer is simplified as spring damping system is evenly distributed between the track plate and track foundation, calculating the parameters of CA mortar: K= 3.4 × 10^7 N/m, Cv=932.7Ns/m. In order to reduce the reflection wave, the element model applied local viscoelastic dynamic artificial boundary element in the computational domain boundaries (Lei and Wei, 2005).

The Load's Simulation of the Subway Train

Wheel/Rail force used in this paper is got by the Kaller calculation theory in the multi-body dynamics software SIMPACK's Wheel/Rail (Rail) module. The SIMPACK vehicle model for Nanchang subway adopts metro B vehicle model parameters. The maximum axle load model is 13 tons. And the designed highest speed is 80Km/h. Load step takes 0.005 s. The integration time interval is 0 to 15 s. So, the paper calculates and draws the curves of wheel/rail forces and power spectrum as Fig. 2. This calculation result is equivalent to Feng Junhe's synthesis by track acceleration method (Feng and Yan, 2008).

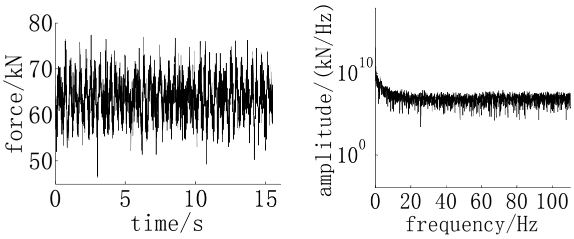

FIG. 2 WHEEL/RAIL FORCE AND FORCE SPECTRUM

Responses Induced by the Buried Depth on Ground Vibration

Due to the different conditions' limitation along the metro lines such as lines planning, construction technology and the geological parameters, the burial depth of the tunnel along the route is changing. So the study of the law of the train vibration induced by different burial depth has a guiding significance. In the finite element model, select a sensitive bit to vibration directly above the tunnel. Vibration spectrum changing with the depth is shown in Fig. 3 to Fig. 7.

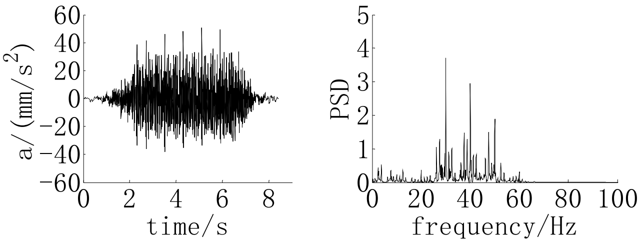

FIG. 3 ACCELERATION AND SPECTRUM OF DEPTH 5m

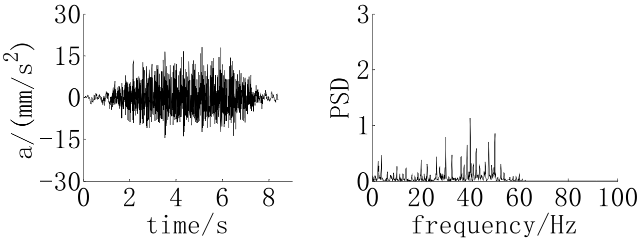

FIG. 4 ACCELERATION AND SPECTRUM OF DEPTH 10m

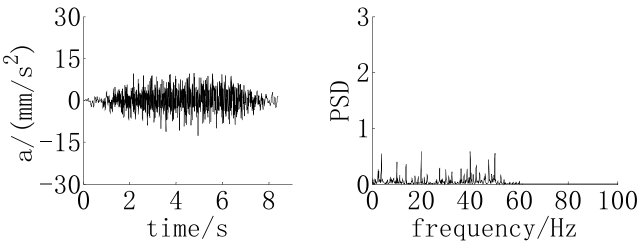

FIG. 5 ACCELERATION AND SPECTRUM OF DEPTH 15m

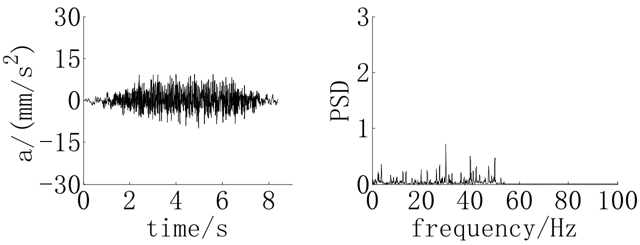

FIG. 6 ACCELERATION AND SPECTRUM OF DEPTH 20m

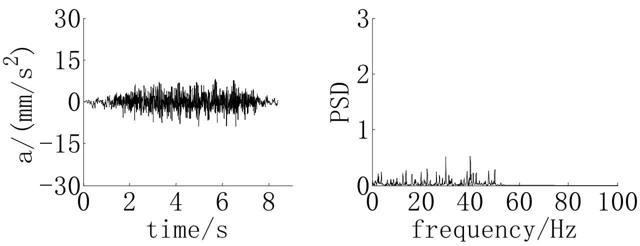

FIG. 7 ACCELERATION AND SPECTRUM OF DEPTH 25m

Fig. 3 to Fig. 7 show the law of vibration in the soft soil, speed 80km/h, uplink and downlink spacing is 15m. From the acceleration curves we can see that the deeper the depth, the smaller the vibration response; the curves become more cyclical when the depths

become shallower. From the Fourier spectrum curves, we can see with the increase of depth, the spectral amplitude in high frequency decries faster than that in the low frequency.

Effects on the Ground Vibration by the Soil Characteristics

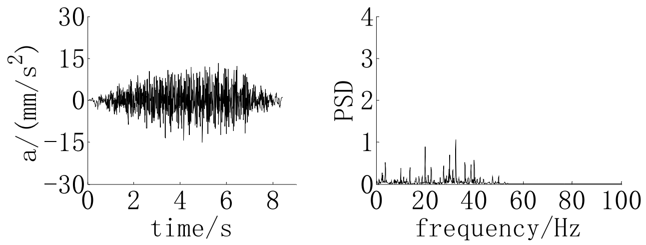

FIG. 8 ACCELERATION AND SPECTRUM OF 95MPa

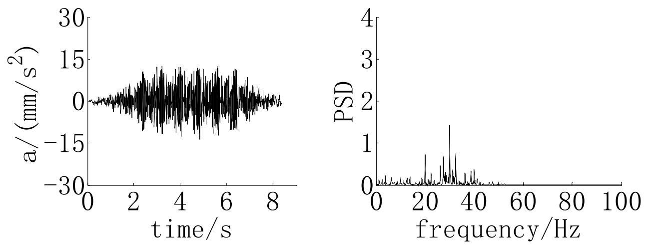

FIG. 9 ACCELERATION AND SPECTRUM OF 165MPa

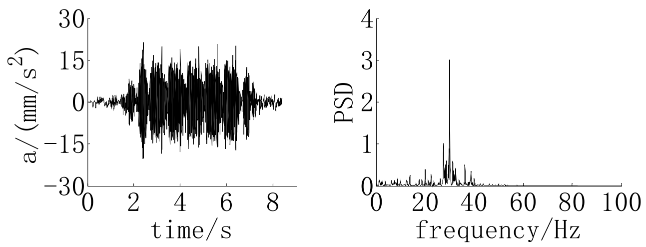

FIG. 10 ACCELERATION AND SPECTRUM OF 235MPa

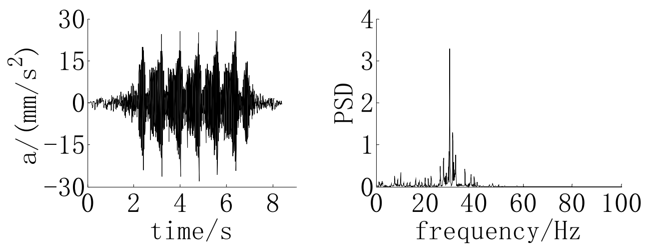

FIG. 11 ACCELERATION AND SPECTRUM OF 305MPa

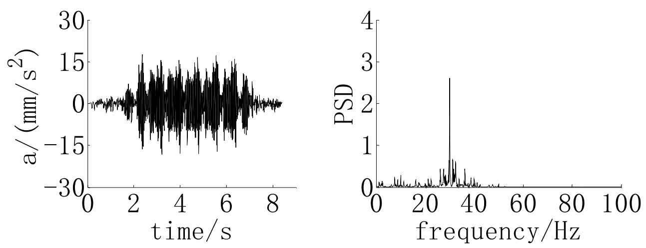

FIG. 12 ACCELERATION AND SPECTRUM OF 375MPa

Urban metro lines connect various counties; however, the geological conditions of different counties will be different. So studying the influence has a practical significance. There are five different soils, select the sensitive points just above the uplink tunnel to analyse. Draw the acceleration curves as shown in Fig. 8 to Fig. 12.

From the acceleration time curves in Fig. 8 to Fig. 12, we can see that when the elastic modulus of soil is 95MPa, the acceleration curve is shaped as a spindle, no periodic variation. When the modulus of elasticity increases gradually from 165MPa to 305MPa, the peak of acceleration increases, and a periodic changing appears; when it increases from 305MPa to 375Mpa, acceleration amplitude decreases gradually, and the periodic acceleration disappears. We can see from the figures, when the soil is very soft, acceleration amplitude spectrum is wide, and ranges in 0-50HZ. Increasing of soil hardness, low frequency gradually decreases; the frequency range becomes narrower and is tend to 31Hz.

This is because when the soil is soft, the dissipation effects on the vibration wave energy are large; the ground vibration frequency is small, and then is close to the low frequency vibration frequency transferred to the wheel/rail force, they produce co-resonances in the low frequency. With the increase of the soil hardness, the natural frequency increases, locates in intermediate frequency which is transferred to the wheel/rail force of soil. When the soil's elastic modulus is 305MPa, self-vibration frequency is close to the predominant frequency of the wheel/rail force going after the fastener and CA mortar's damping, so the vibration response reaches a maximum value. But with the continue increasing of the soil elastic modulus, the self-vibration natural frequency of is further more higher than the predominant frequency that transferred to the wheel/rail force , so the response of ground vibration reduces, and produce the phenomenon of low frequency vibration wave in the hard soil is filtered out .

The Net Distance's Effects on the Ground Vibration between Uplink and Downlink

Nanchang subway line vertical distances from the line to another along the line are extending from 10m to 25m. Analysing the ground vibration caused by the different net distances between the uplink and downlink can provide reference to the following design. In the finite element model, authors control the net distances, and select a sensitive bit to vibration which is both 15 m from two lines. Draw the acceleration curve shown in Fig. 13 to Fig. 17.

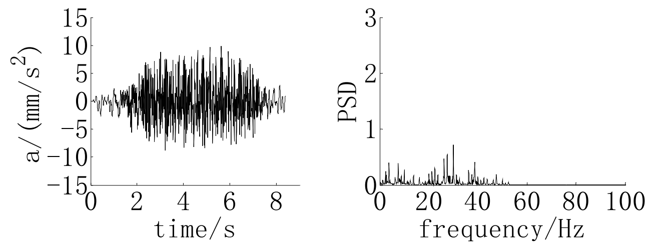

FIG. 13 ACCELERATION AND SPECTRUM OF DISTANCE 8m

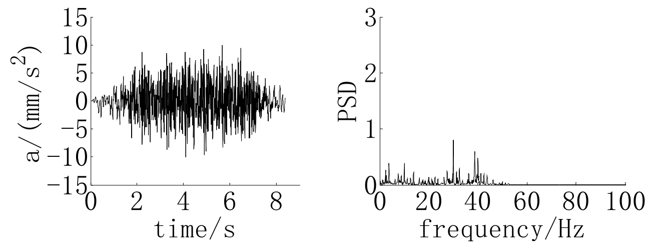

FIG. 14 ACCELERATION AND SPECTRUM OF DISTANCE 12m

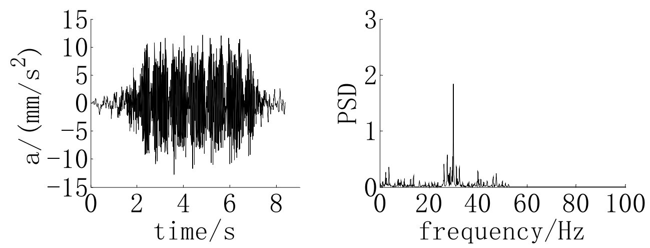

FIG. 15 ACCELERATION AND SPECTRUM OF DISTANCE 16m

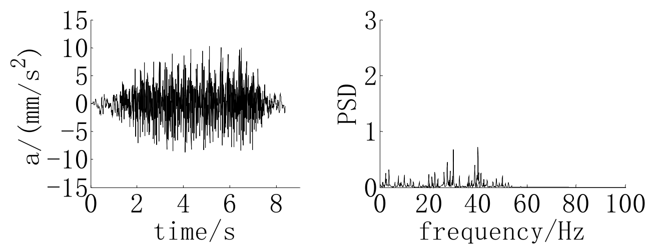

FIG. 16 ACCELERATION AND SPECTRUM OF DISTANCE 20m

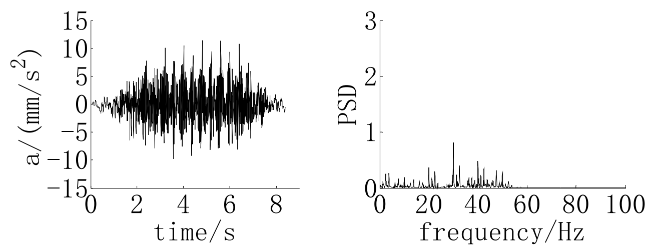

FIG. 17 ACCELERATION AND SPECTRUM OF DISTANCE 24m

From above figures we can find that with the increase of tunnel net spacing, peak acceleration reduces, but when the net spacing is 16 m, sensitive vibration response has an amplification phenomenon, which is consistent with Yan Weiming's testing results (Yan and Zhang et al., 2006). Studies have suggested that this is due to that waves in the soil have repeated reflection. When the net spacing is 20 m and the downlink is 25 m far from the sensitive bit, the uplink is 5 m far from the sensitive bit, and then the vibration response is mainly caused by the closer line. Therefore, when a line of double line tunnel is far more than 25m from the sensitive points, designers can only consider the influence of the nearby tunnel.

Conclusion

In this paper, we can get the following conclusions: Firstly, effects of buried depth on the ground vibration response are obvious. The shallower the buried depth, the greater the surface vibration acceleration is. If the cost and construction conditions permit, authors propose increasing the depth to reduce the ground vibration in the vibration sensitive area. Secondly, the soil modulus of elasticity is one of the important factors that affect the ground vibration responses. Modulus of elasticity increases from 95 Mpa to 305 Mpa, the acceleration increases; when the modulus of elasticity increases from 305 Mpa to 445 Mpa, and the acceleration decreases. Finally, the clear distance between uplink and downlink has much effect on the ground vibration response. If one line of uplink and downlink is 25m far away the sensitive point, designers can only consider the influence of the nearby lines.

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